SUGAR: A MEMS Simulation Program

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SUGAR contributors

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Overview

- Background, target applications, grand vision
- Simple cantilever beam example
- A bigger example: analysis of a micromirror
- Ongoing work: measurement feedback, synthesis, web-based simulation

Levels of simulation

- Solve continuum equations (momentum conservation, Maxwell's, etc.)
- Solve simplified equations of beam and plate theory (structural elements)
- Solve network equations (e.g. modified nodal analysis in SPICE; Simulink models)
- These approaches are not mutually exclusive!
- Share similar software structures

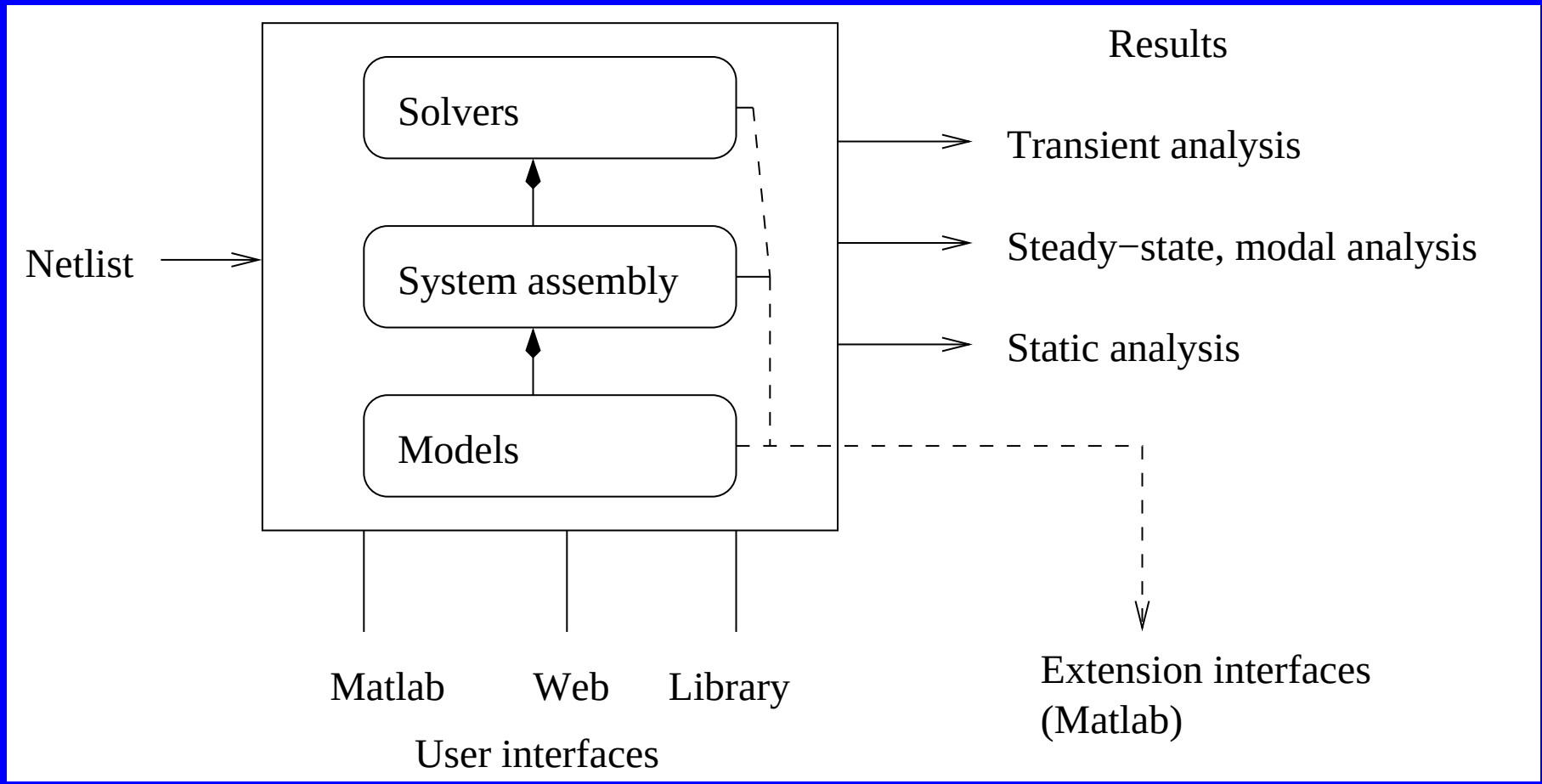
Where does SUGAR fit?

- Primarily simulates electromechanical systems
- Has element models at the structural and network levels
- Provides a flexible language for device description
- Performs static, frequency-response, modal, and (some) transient analysis
- Can build quick models that get high-level behavior

Where does SUGAR fit?

- Freely available and open source
  - `www.sourceforge.net/project/mems`
  - `sugar.millennium.berkeley.edu`
- Useful for education and prototyping
- Building block for higher-level operations
  - e.g. Design synthesis and optimization
- Part of work to “close design loop”
  - Simulation (SUGAR)
  - Measurement instruments

SUGAR architecture



SUGAR: Recent evolution

- Early 01: SUGAR 2.0 released
- Summer 01: Initial involvement of SUGAR group with Matisse
- Summer 01: Development of first public version of M&MEMS
- Fall 01: M&MEMS used for EE 245
- Winter 02: Initial version of SUGAR 3.0
- Winter 02: N. Zhou finished thesis (GA synthesis of MEMS)
- Spring 02: SUGAR 3.0 public release

SUGAR: Near-term development

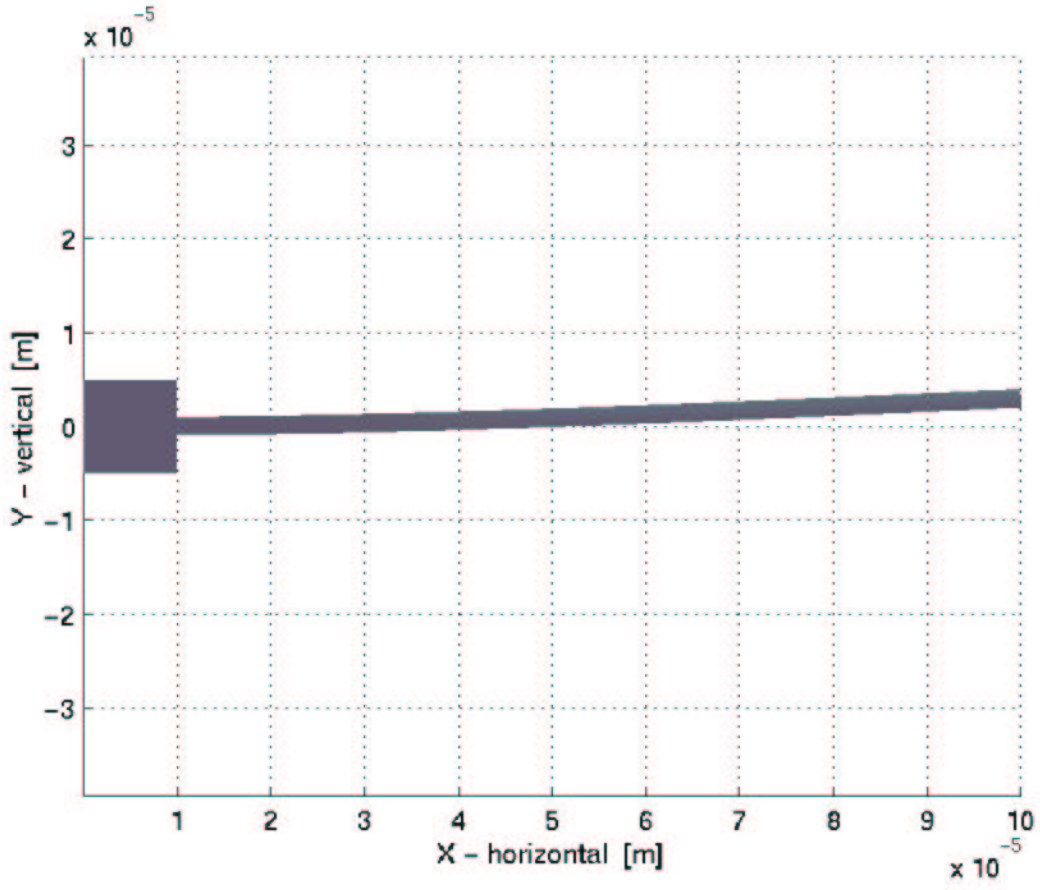
- Finish non-Matlab SUGAR 3.0 version
- Rebuild M&MEMS with SUGAR 3.0
- Build optical measurement comparison framework
- Finish several models in development (plates, improved electrostatics)
- Move “user” codes to SUGAR 3.0 (e.g. simulated annealing synthesis code and Monte-Carlo based sensitivity analysis code)

Running a simple analysis

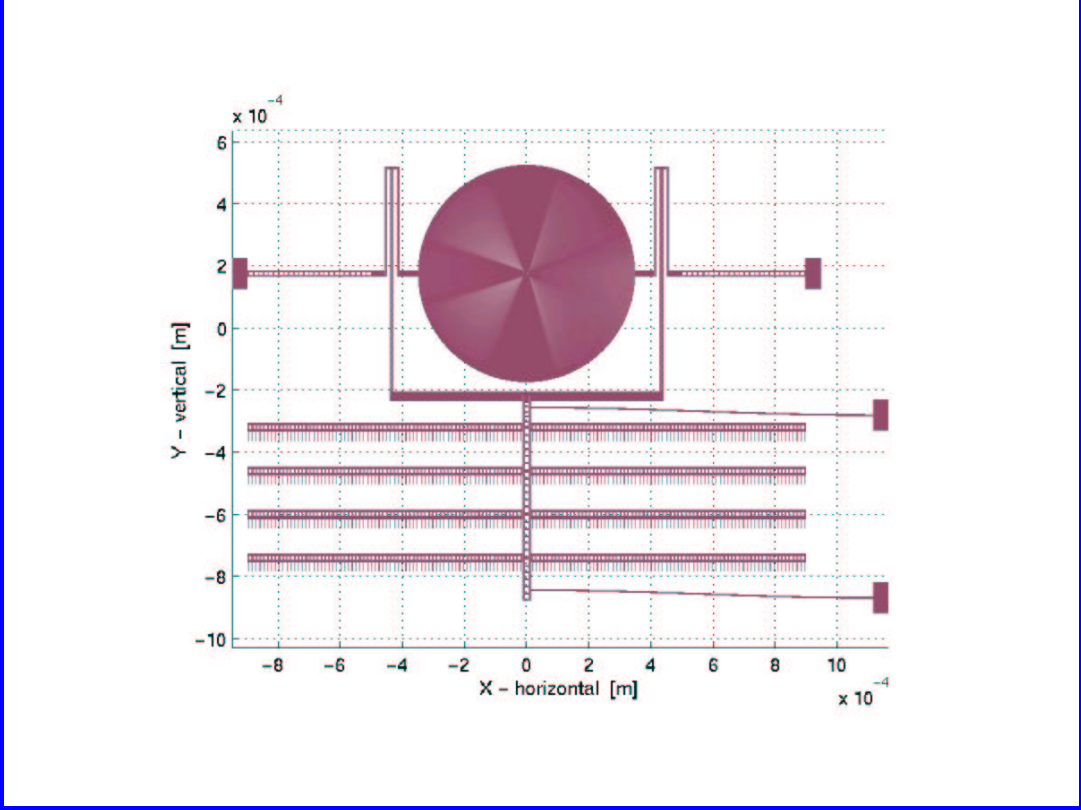
```
net = cho_load('cantilever.net');
cho_display(net);
dq = cho_dc(net);
cho_display(net, dq);
dy = cho_dq_view(dq,net,'tip','y')
```

- Load and display device description
- Analyze and display static displacement
- Get y-displacement of tip

Deflected cantilever

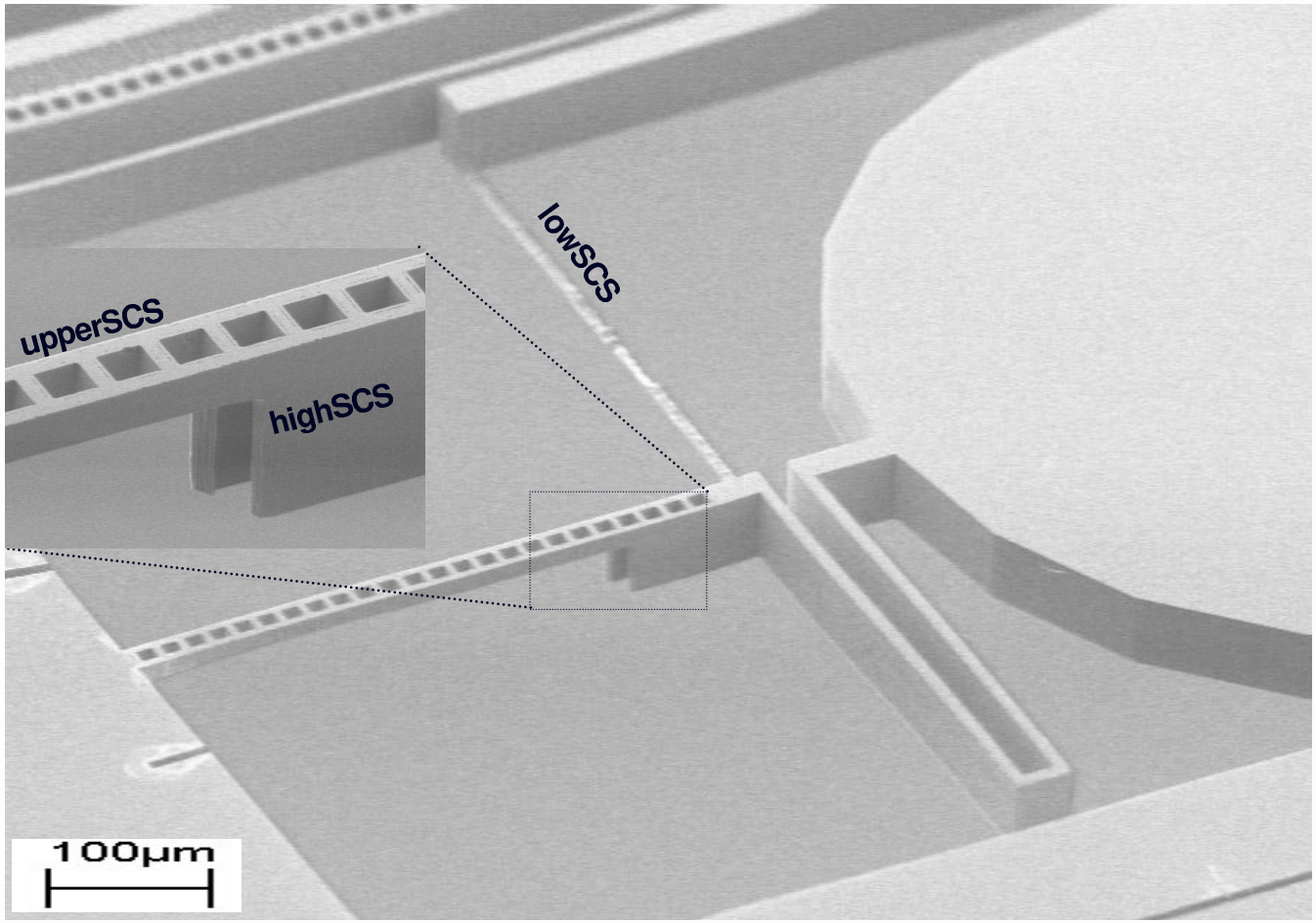


A bigger example

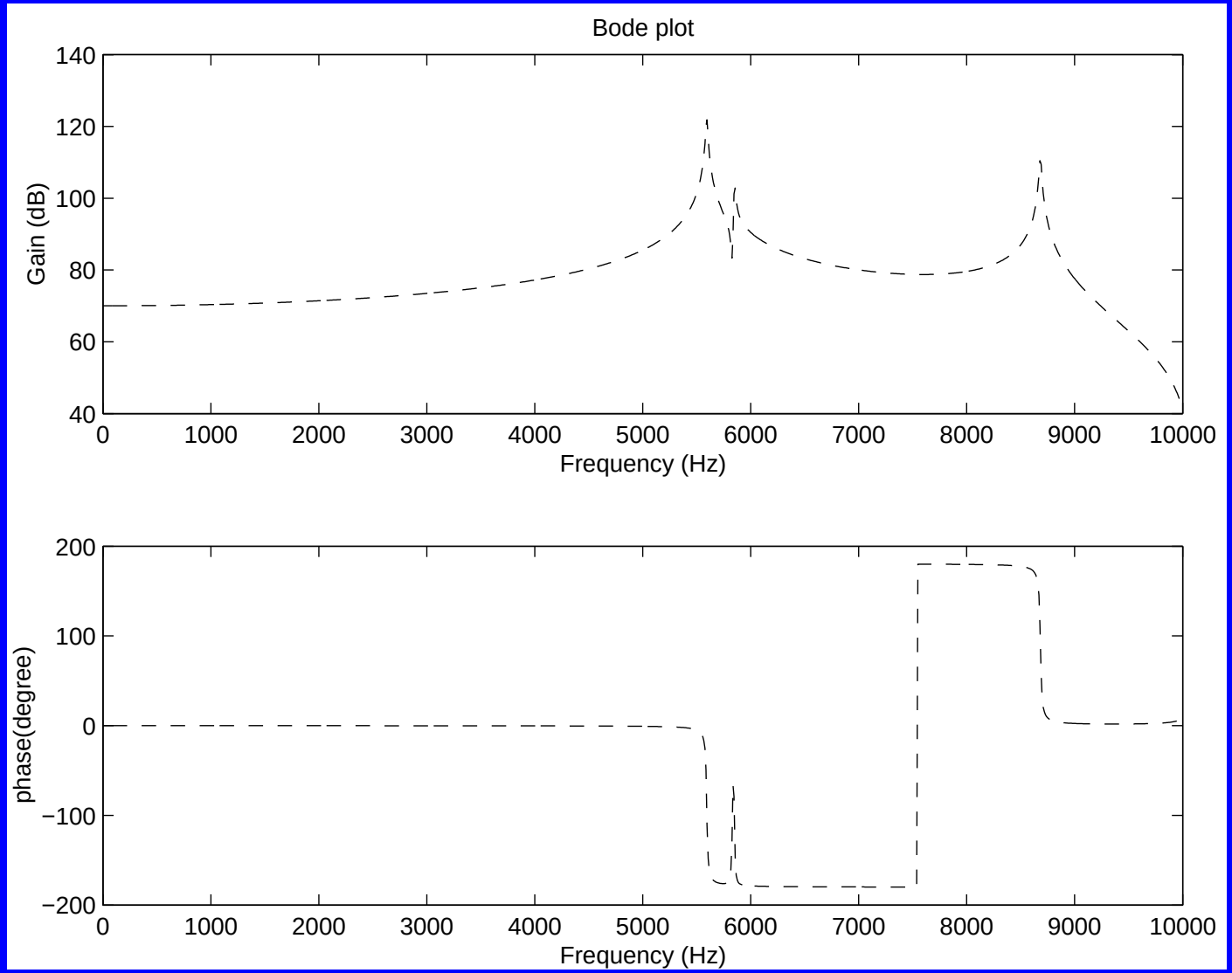


- Micromirror design due to Matt Last
- Model has roughly 11K degrees of freedom

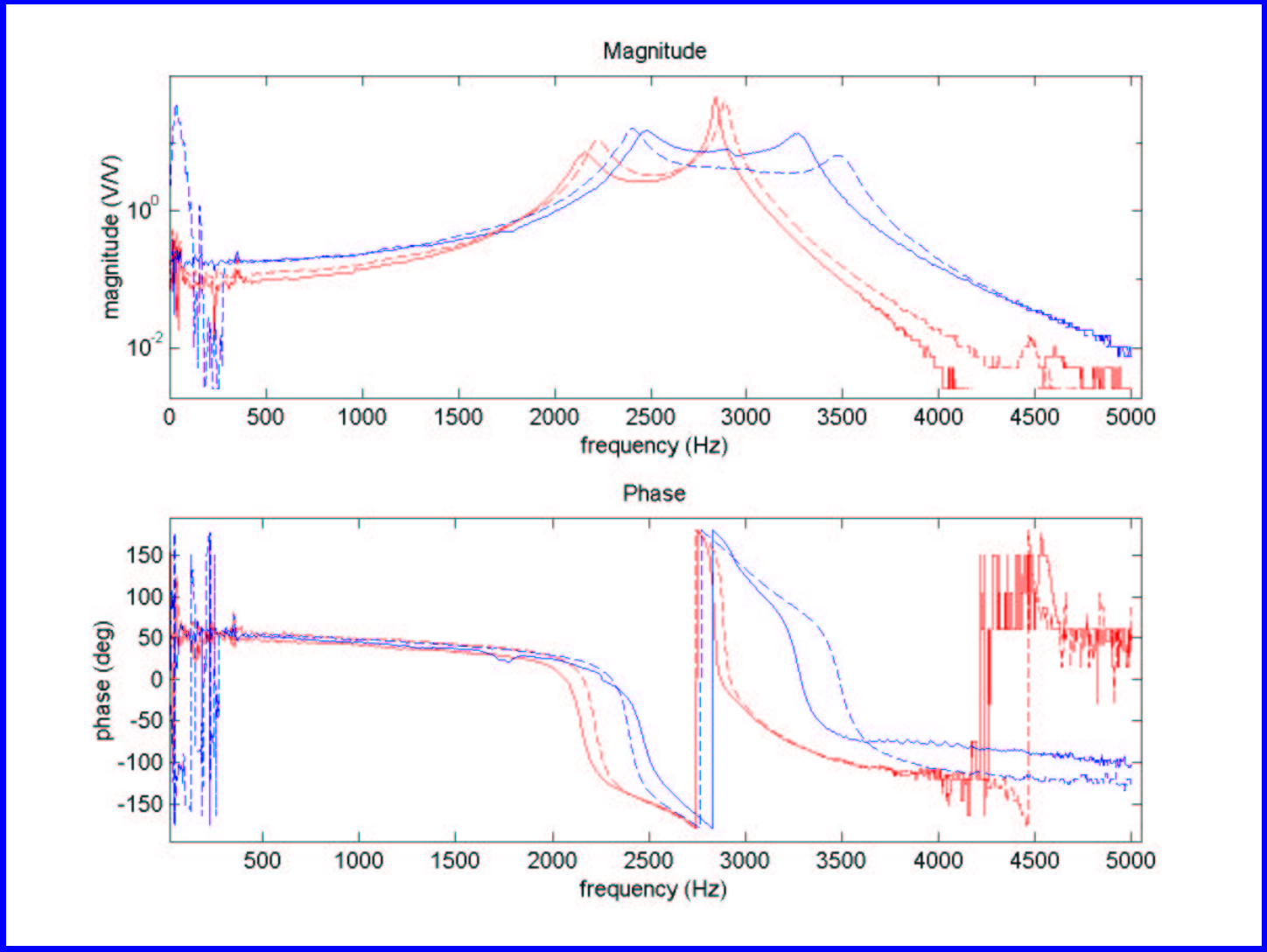
Micromirror SEM



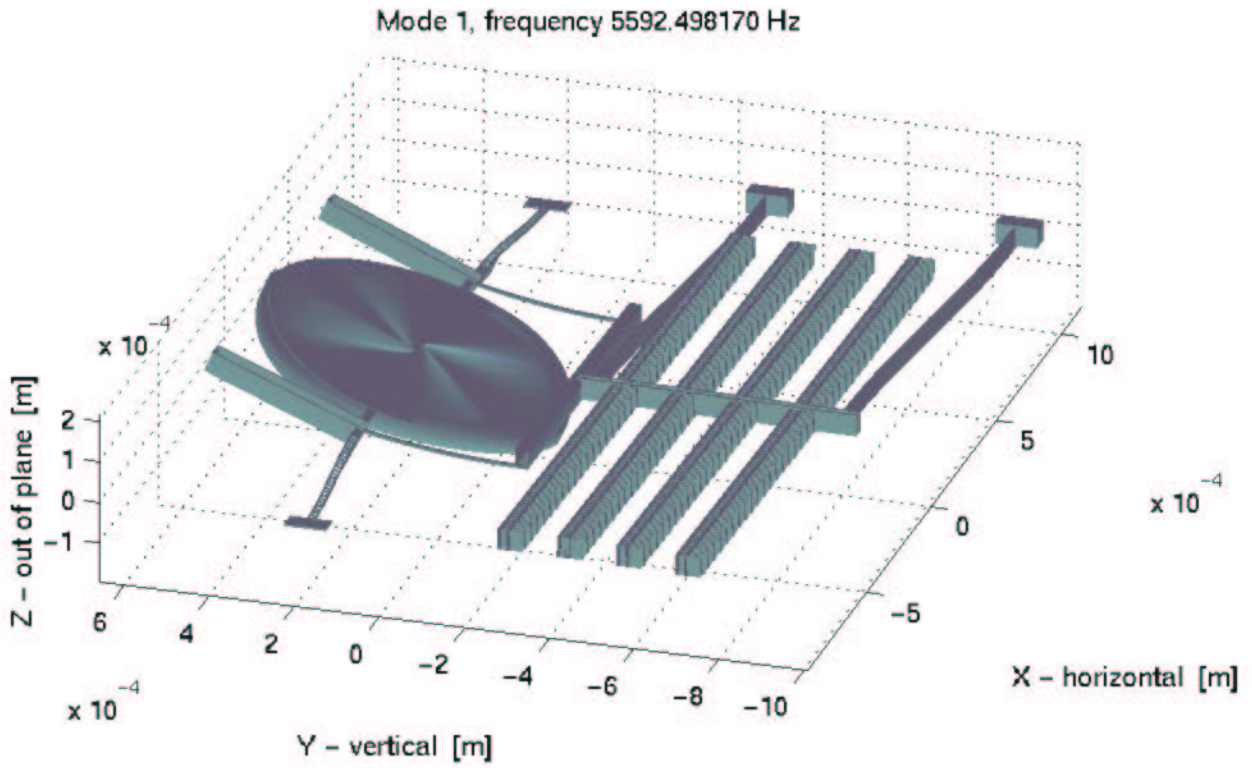
Simulated frequency response



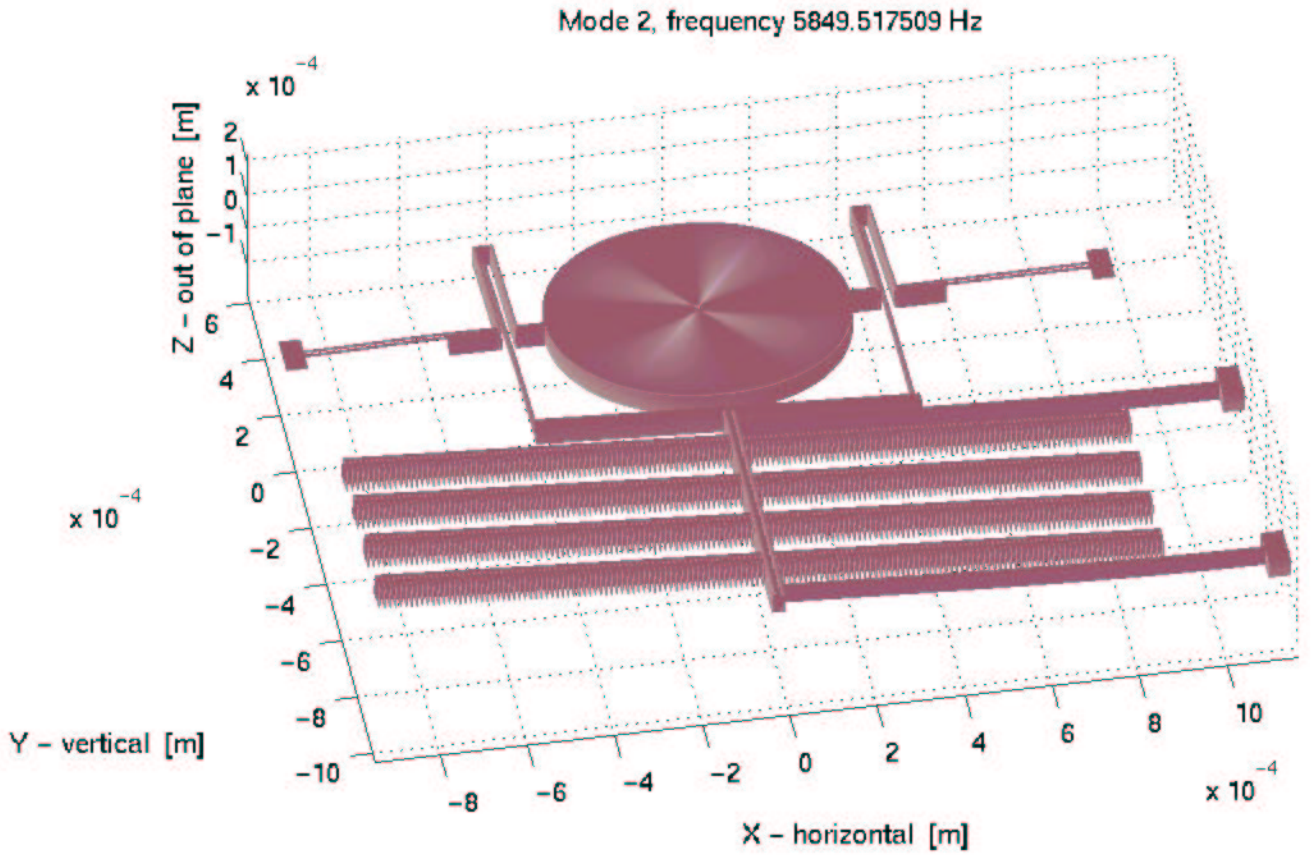
Measured frequency response



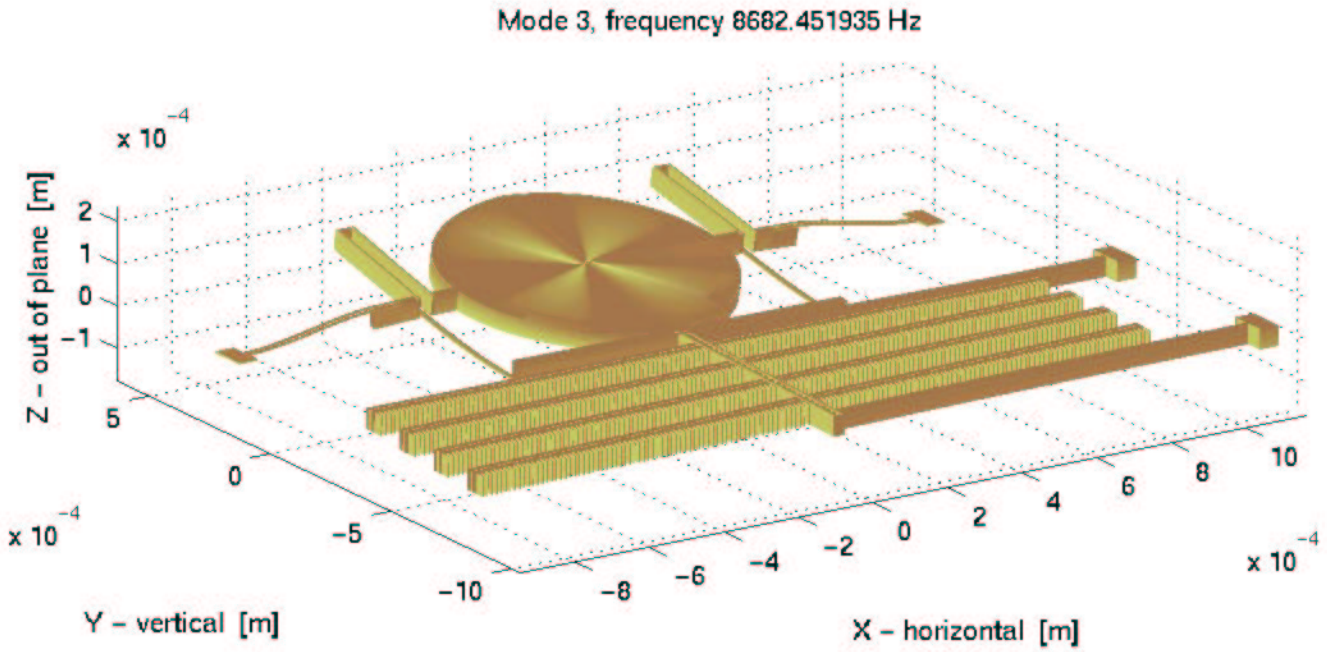
First resonant mode



Second resonant mode



Third resonant mode



Existing models

- Mechanical: anchor, beam2d, beam3d, f2d, f3d, rigid, constraint
- Electrical: L, R, C, Isrc, Vsrc, opamp, vcvs
- Coupled: comb2d, gap2dforce, gap3dforce
- Subnets: beam2de, beam3de, gap2de, gap3de

Models under construction

- Plates
- Simple hinges and sliders
- Anisotropic beams
- Nonlinear beams
- Thermal circuit analogues
- Electrothermal and thermomechanical

Future models

- Contact models
- Improved damping
- Wrappers around FEAP models
- Controllers

Analyses

- Current
  - Static equilibrium
  - Steady-state frequency-response analysis
  - Modal analysis
  - Transient analysis (2.0)
- Future
  - Sensitivity (various flavors)
  - Bifurcation analysis

Ongoing numerical work

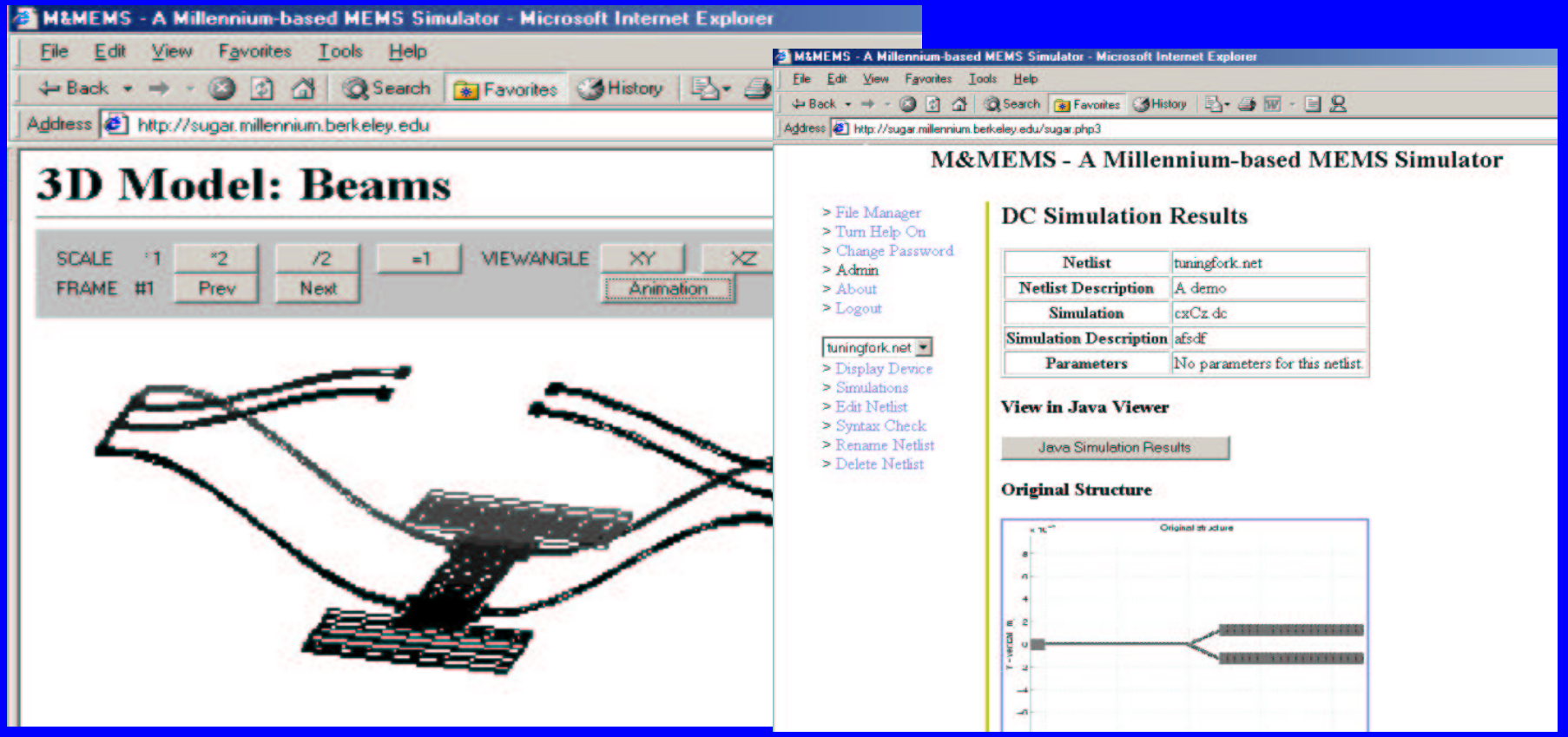
- Have adopted standard sparse solver packages for linear solves and modal analysis
- Reduced order modeling techniques (used for mirror steady-state response analysis)
- Incorporating newest DAE solvers (IDA); parameter sensitivity for DAEs
- Bifurcation analysis of DAE systems
- CIS algorithm for large-scale bifurcation analysis
- Dealing with multi-scale problems
- Building test case library

Closing the design loop

- Integrate measurement and simulation facilities
  - R. Muller, R. Kant, C. Rembe, M. Young working on measurements at UCB
  - Other groups at CMU, MIT, Sarnoff
- Feedback measured data into simulation, design
  - Compare simulation and reality
  - Parameter extraction, sensitivity studies
- Make facilities available as a “virtual lab”

M&MEMS: SUGAR on the Web

http://sugar.millennium.berkeley.edu/



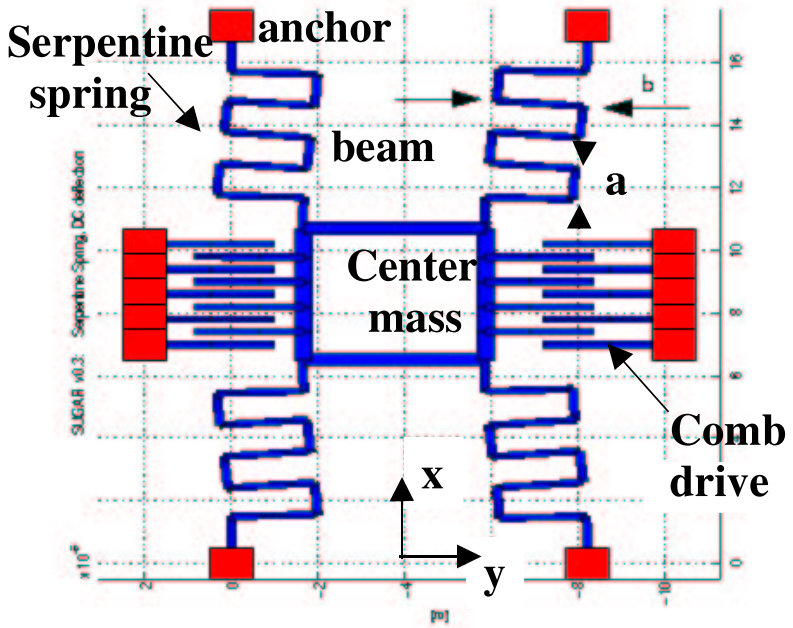
M&MEMS

- Hosted on UCB Millennium cluster
- Used in Introduction to MEMS course, Fall 2001
- Accounts available for outside users
- Currently offline while upgrading to SUGAR 3.0

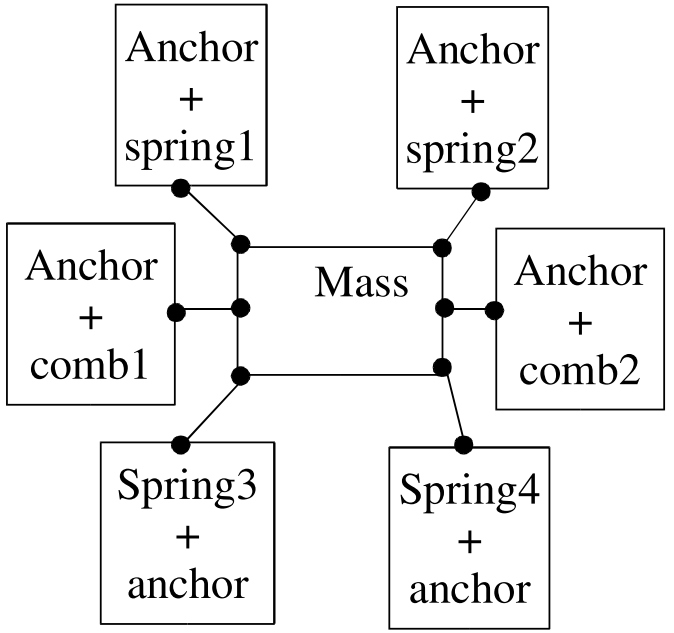
Design synthesis and optimization

- Genetic algorithms to evolve new designs
- Also simulated annealing approach
- Specializing designs from a library
- N. Zhou, B. Zhu, A. Agogino, and K. Pister: “Evolutionary Synthesis of MEMS (Microelectronic Mechanical Systems) Design” (ANNIE 2001). First Runner-up for Novel Smart Engineering System Design Award.

Functional decomposition and GA



(a) **MEMS resonator with four meandering springs**



(b) GA Building blocks and their connectivity

Conclusion

- Web links
  - `bsac.eecs.berkeley.edu/~cfm`
  - `www.sourceforge.net/project/mems`
  - `sugar.millennium.berkeley.edu`
- SUGAR is actively used
  - Educationally
  - For prototyping and exploring
  - As a testbed for larger projects